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## **Introduction**

The follow tasks were completed under this contract:

Lightning network data and information were collected from: The U.S., Germany, France, Brazil, China and Australia towards the development of a Global Lightning Data Base.

Media publications were written, edited and produced to describe lightning detection from space. These publications include two two-sided lithograph-type glossy picture handouts which describe the Optical Transient Detector and the Lightning Imaging Sensor.

A color brochure describes the history of lightning research and related investigations.

Travel to New Mexico and Wallops Flight Facility, Virginia were conducted by the contractor to collect both lightning network information and to help define the tasks of lightning detection studies by high altitude aircraft and satellite instrumentation.

Copies of all publications are attached and made a part of this report, awaiting final approval and printing by NASA.

## **Lightning Detection from Space**

## READING LIGHTNING'S PALM

Outside this ragged darkening cloud  
air grows heavy, cringes  
while inside, tension builds

a forked tongue flickers  
squanders all  
in one great leap to earth  
or to the heavens

air breathes out  
-but inside the cloud  
tension builds again.

This story older  
than recorded history  
dinosaurs  
our planet's green  
-the spark, perhaps  
that kindled life.

Looking up, we see it  
rip the helpless sky,  
we marvel at its power  
to scorch forests  
wreck cathedrals  
put out a city's lights  
weave glass serpents  
in the desert sand.

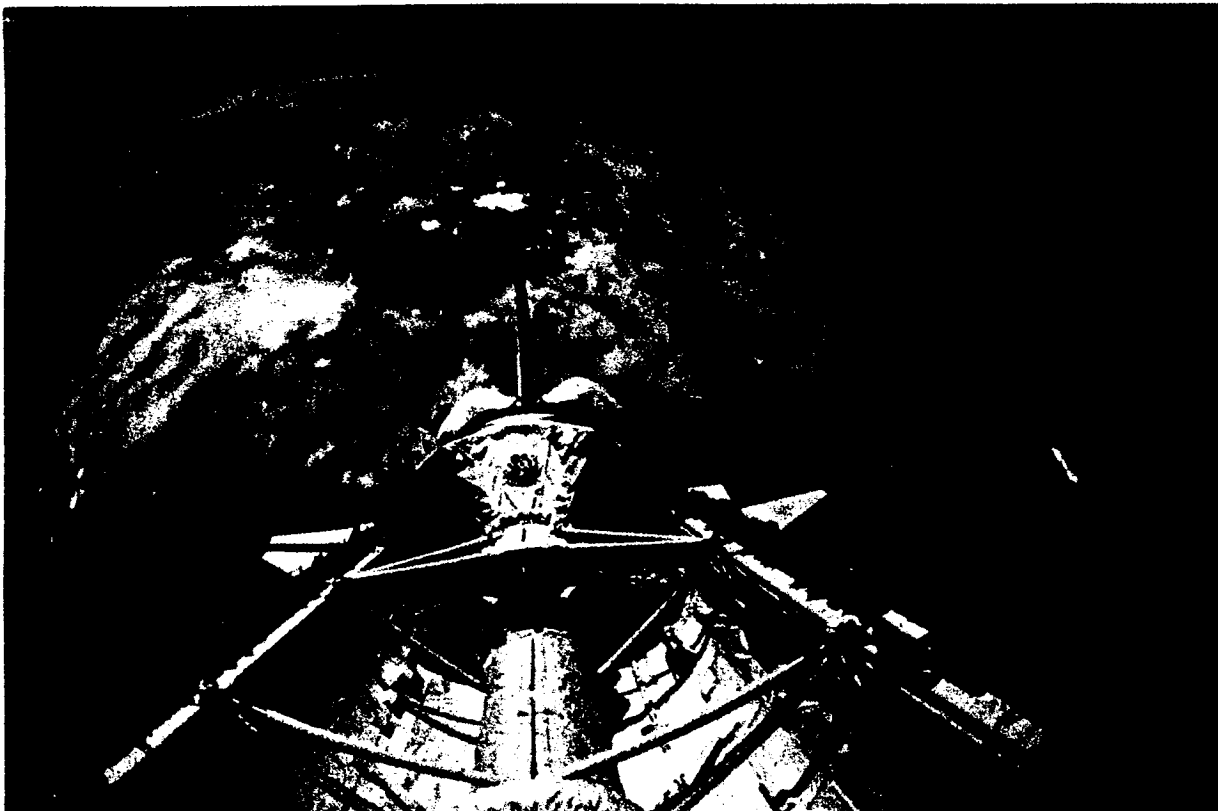
Looking down, as now we can,  
our globe scintillates  
always  
-flurries of dagger-strokes  
accompanying great storms  
over oceans  
jungles, mountains

a fireworks show  
blazoning messages  
in code  
which we must crack.

J. Latham

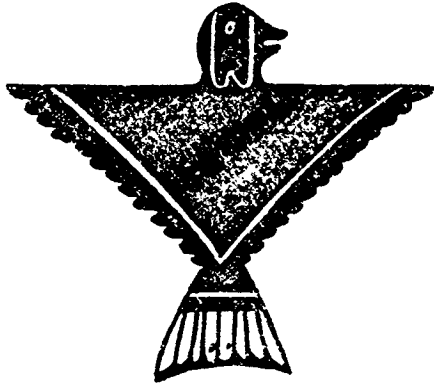
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## INTRODUCTION

Lightning, the thunderbolt from mythology, has long been feared as an atmospheric flash of supernatural origins: the great weapon of the gods. The Greeks both marveled and feared lightning as it was hurled by Zeus. For the Vikings, lightning was produced by Thor as his hammer struck an anvil while riding his chariot across the clouds. In the East, early statues of Buddha show him carrying a thunderbolt with arrows at each end. Indian tribes in North America believed that lightning was due to the flashing feathers of a mystical THUNDERBIRD whose flapping wings produced the sound of thunder.



Today, scientific rather than mystical techniques are used to explain lightning with experimental procedures replacing intuitive concepts. Yet, we remain in awe of lightning which still shines with its mystery, and rightly so. Each year, lightning is responsible for the deaths of a hundred or so people, injuries to several hundred more, and millions of dollars in property damage, in the United States alone.

While these are more than sufficient reasons for NASA to pursue lightning research, lightning has a direct affect on day-to-day operations as well. The avoidance of lightning strikes to a spacecraft during launch relies heavily on the ability of meteorologists to accurately forecast and interpret lightning hazards to NASA vehicles under varying weather situations. Severe hazards for NASA due to lightning have been well documented. One major incident occurred during the 1969 launch of the Apollo 12 mission when lightning briefly knocked out vital spacecraft electronics. Fortunately, the astronauts regained control.

The unmanned Atlas Centaur 67 which carried a Naval communication satellite was determined to have been struck by a triggered cloud-to-ground lightning flash on March 26, 1987. The lightning current apparently altered memory in the digital flight control computer. This glitch resulted in the generation of a hard-over yaw command which caused an excessive angle of attack, large dynamic loads, and ultimately the breakup of the vehicle.

On a smaller scale, two sounding rockets being prepared for launch from NASA's Wallops Island in 1987 were prematurely launched as a direct result of lightning.

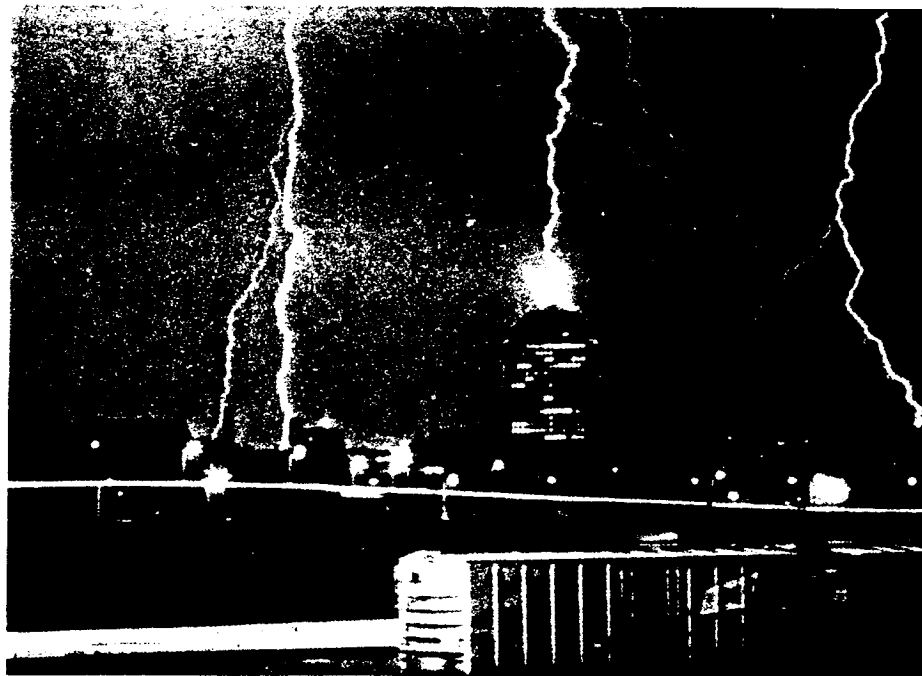
It is now well recognized that lightning strikes to aircraft most often originate from the craft itself. The flash is believed to begin with the inception of a leader, propagating in both directions away from the craft. These are called "triggered" lightning flashes.



It is difficult to obtain accurate statistics on lightning injuries and fatalities since a systematic compilation of information on lightning casualties does not exist. Many case histories show heart damage. Inflated lungs and brain damage have also been observed from lightning fatalities. Loss of consciousness, amnesia, paralysis and burns are reported by many who have survived.

Deaths and injuries to livestock and other animals, thousands of forest and brush fires, as well as millions of dollars in damage to buildings, communications systems, power lines, and electrical systems are also the result of lightning.

Finally, the threat of lightning causes many work stoppages and lost production increasing the time and cost required to prepare NASA spacecraft for flight.



## HISTORY

Benjamin Franklin performed the first systematic, scientific study of lightning during the second half of the 18th century. Prior to that time, electrical science had developed to the point where positive and negative charges could be separated. Electrical machines could, by rubbing together two different materials, store the charges in primitive capacitors called Leyden Jars from which sparks could be generated and observed.

While others had previously noted the similarity between laboratory sparks and lightning, Franklin was the first to design an experiment which conclusively proved the electrical nature of lightning. In his experiment, he theorized that clouds are electrically charged, from which it follows that lightning must also be electrical. The experiment involved Franklin standing on an electrical stand, holding an iron rod with one hand to obtain an electrical discharge between the other hand and the ground. If the clouds were electrically charged then sparks would jump between the iron rod and a grounded wire, in this case, held by an insulating wax candle.

This experiment was successfully performed by Thomas Francois D'Alibard of France in May 1752 when sparks were observed to jump from the iron rod during a thunderstorm. G. W. Richmann, a Swedish physicist working in Russia during July 1753, proved that thunderclouds contain electrical charge, and was killed when lightning struck.

Before Franklin accomplished his original experiment, he thought of a better way to prove his hypothesis-an electrical kite. The kite took the place of the iron rod, since it could reach a greater elevation and could be flown anywhere. During a Pennsylvania thunderstorm in 1752 the most famous kite in history flew with sparks jumping from a key tied to the bottom of damp kite string to an insulating silk ribbon tied to the knuckles of Franklin's hand. Franklin's grounded body provided a conducting path for the electrical currents responding to the strong electric field buildup in the storm clouds.

In addition to showing that thunderstorms contain electricity, by measuring the sign of the charge delivered through the kite apparatus, Franklin was able to infer that while the clouds were overhead, the lower part of the thunderstorm was generally negatively charged.



Little significant progress was made in understanding the properties of lightning until the late 19th century when photography and spectroscopic tools became available for lightning research.

Lightning current measurements were made in Germany by Pockels (1897-1900) who analyzed the magnetic field induced by lightning currents to estimate the current values. Time-resolved photography was used by many experimenters during the late 19th century to identify individual lightning strokes that make up a lightning discharge to the ground.

Lightning research in modern times dates from the work of C.T.R. Wilson who was

the first to use electric field measurements to estimate the structure of thunderstorm charges involved in lightning discharges. Wilson, who won the Nobel Prize for the invention of the Cloud Chamber, made major contributions to our present understanding of lightning.

Research continued at a steady pace until the late 1960's when lightning research became particularly active. This increased interest was motivated both by the danger of lightning to aerospace vehicles and solid state electronics used in computers and other devices as well as by the improved measurement and observational capabilities which were made possible by advancing technology.

## CHARACTERISTICS OF A STORM

### LIGHTNING

As the particles within a cloud (called hydrometeors) grow and interact, some become charged possible through collisions. It is thought that the smaller particles tend to acquire positive charge, while the larger particles acquire more negative charge. These particles tend to separate under the influences of updrafts and gravity until the upper portion of the cloud acquires a net positive charge and the lower portion of the cloud becomes negatively charged. This separation of charge produces enormous electrical potential both within the cloud and between the cloud and ground. This can amount to millions of volts, and eventually the electrical resistance in the air breaks down and a flash begins. Lightning, then, is an electrical discharge between positive and negative regions of a thunderstorm.

A lightning flash is composed of a series of strokes with an average of about four. The length and duration of each lightning stroke vary, but typically average about 30 microseconds. (The average peak power per stroke is about  $10^{12}$  watts.)

### THUNDER

Sound is generated along the length of the lightning channel as the atmosphere is heated by the electrical discharge to the order of  $20,000^{\circ}\text{C}$  (3 times the temperature of the surface of the sun). This compresses the surrounding clear air producing a shock wave, which then decays to an acoustic wave as it propagates away from the lightning channel.

Although the flash and resulting thunder occur at essentially the same time, light travels at 186,000 miles in a second, almost a million times the speed of sound. Sound travels at the relatively snail pace of one-fifth of a mile in the same time. Thus the flash, if not obscured by clouds, is seen before the thunder is heard. By counting the seconds between the flash and the thunder and dividing by 5, an estimate of the distance to the strike (in miles) can be made.

### CLOUDS AND RAIN

When moisture-laden warm air is heated, it begins to rise. As these currents or bubbles of warm moist air rise higher in the atmosphere both the surrounding air pressure and temperature decrease. The air bubbles expand, causing cooling of the moisture which eventually condenses to form clouds. As the cloud cools further, more moisture condenses and the water droplets making up the cloud grow and merge until some become so large and heavy that the air currents within the cloud can no longer support them. They begin to fall as rain.

### HAIL

Air currents in cumulonimbus clouds can be very violent. Even when lightning is not produced, pellets of ice may grow by the accumulation of liquid droplets. When the updrafts are very strong, the growing ice pellets can be suspended for long periods, allowing them to grow larger. Eventually some may become too large for a given updraft and begin to fall as hail. Diameters are typically 5 to 10 mm, although a 140 mm hailstone has been recorded.

## TYPES OF LIGHTNING DISCHARGES

**CLOUD-TO-GROUND LIGHTNING** is the most damaging and dangerous form of lightning. Although not the most common type, it is the one which is best understood. Most flashes originate near the lower-negative charge center and deliver negative charge to Earth. However, an appreciable minority of flashes carry positive charge to Earth. These positive flashes often occur during the dissipating stage of a thunderstorm's life. Positive flashes are also more common as a percentage of total ground strikes during the winter months.

**INTRA-CLOUD LIGHTNING** is the most common type of discharge. This occurs between oppositely charged centers within the same cloud. Usually the process takes place within the cloud and looks from the outside of the cloud like a diffuse brightening which flickers. However, the flash may exit the boundary of the cloud and a bright channel, similar to a cloud-to-ground flash, can be visible for many miles.

The ratio of cloud-to-ground and intra-cloud lightning can vary significantly from storm to storm. Storms with the greatest vertical development may produce intra-cloud lightning almost exclusively. Some suggest that the variations are latitude-dependent, with a greater percentage of cloud-to-ground strikes occurring at higher latitudes. Others suggest that cloud-top height is a more important variable than latitude.

Details of why a discharge stays within a cloud or comes to ground are not understood. Perhaps a flash propagates toward the Earth when the electric field gradient in the lower regions of the cloud is stronger in the downward direction.

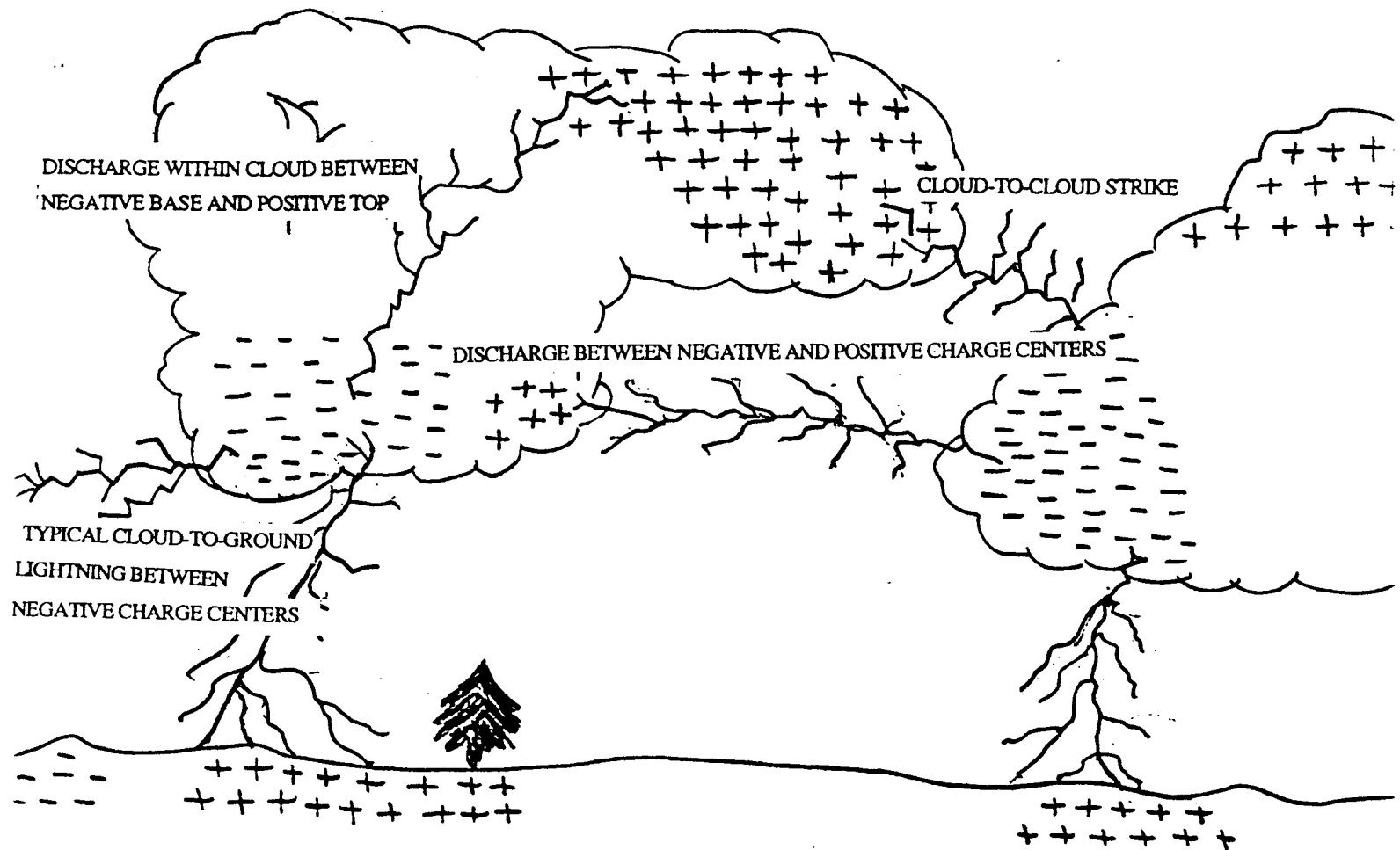
Depending upon cloud height above ground and changes in electric field strength between cloud and Earth, the discharge stays within the cloud or makes direct contact with the Earth. If the field strength is highest in the lower regions of the cloud a downward flash may occur from cloud to Earth.

**INTER-CLOUD LIGHTNING**, as the name implies, occurs between charge centers in two different clouds with the discharge bridging a gap of clear air between them.

## OTHER TYPES OF LIGHTNING

There are numerous names and descriptions of various types and forms of lightning. Some identify subcategories, and others may arise from optical illusions, appearances, or myths. Some popular terms include:

**ball lightning**  
**heat lightning**  
**bead lightning**  
**sheet lightning**  
**silent lightning**  
**black lightning**  
**ribbon lightning**  
**colored lightning**  
**tubular lightning**  
**meandering lightning**  
**cloud-to-air lightning**  
**stratospheric lightning**



*The lower part of a thundercloud is usually negatively charged. The upward area is usually positively charged. Lightning from the negatively charged area of the cloud generally carries negative charge to Earth and is called a negative flash. A discharge from a positively-charged area to Earth produces a positive flash.*

## DESCRIPTION OF LIGHTNING DISCHARGE PROCESSES

With the initial breakdown of the air in a region of strong electric fields, a streamer may begin to propagate downward toward the Earth. It moves in discrete steps of about 50 meters each and is called a *stepped leader*. As it grows, it creates an ionized path depositing charge along the channel, and as the *stepped leader* nears the Earth, a large potential difference is generated between the end of the leader and the Earth. Typically, a streamer is launched from the Earth and intercepts the descending *stepped leader* just before it reaches the ground. Once a connecting path is achieved, a return stroke flies up the already ionized path at close to the speed of light. This return stroke releases tremendous energy, bright light and thunder. Occasionally, where a thunderstorm grows

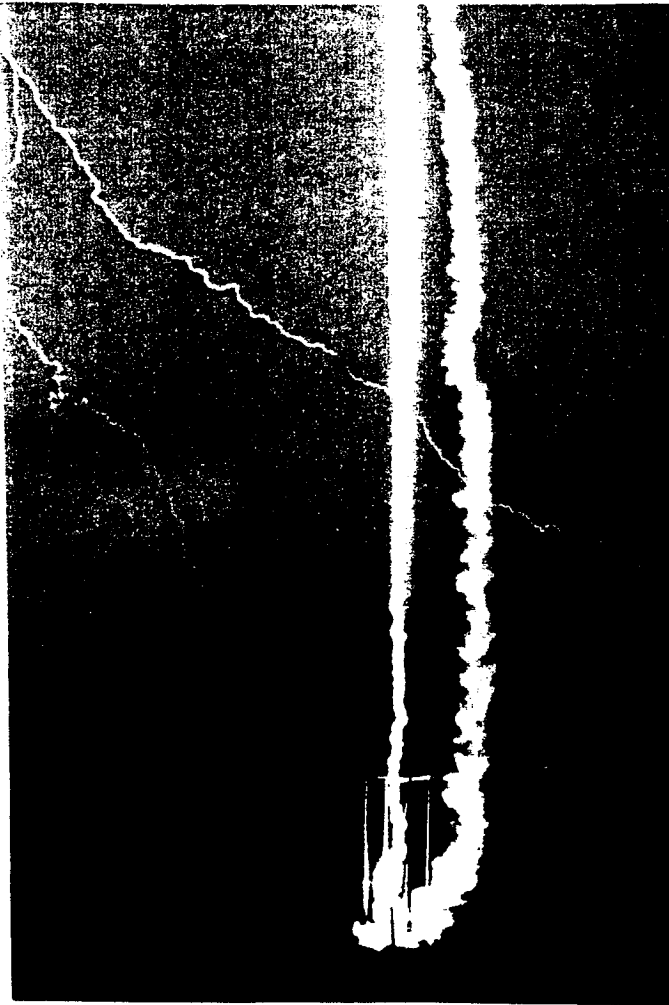
over a tall Earthed object, such as a radio antenna, an upward leader may propagate from the object toward the cloud. This "ground-to-cloud" flash generally transfers a net positive charge to Earth and is characterized by upward pointing branches.

The initial breakdown and propagation are similar for intra-cloud lightning, but the discharge generally occurs between regions of opposite charge. Without the benefit of air conducting Earth, intra-cloud lightning does not produce a return-stroke-like feature. Rather, it is characterized by slower propagating "recoil streamers" and "K" changes. Nevertheless, tremendous energy, bright light, and thunder are still produced by intra-cloud lightning.

## LIGHTNING INVESTIGATIONS USING ROCKETS, HIGH-ALTITUDE AIRPLANES AND SPACECRAFT

For many investigations, lightning must be observed from as close a vantage point as possible. One technique is to probe inside of hostile thunderstorms in order to study how thunderclouds electrify, but this does not ensure close-up encounters with lightning. Close-up measurements are difficult to obtain because of the unpredictability of where and when lightning will strike. Hence, methods have been developed to create lightning discharges under somewhat controlled conditions.

Rocket-triggered lightning research has been an important tool for close-up investigation.



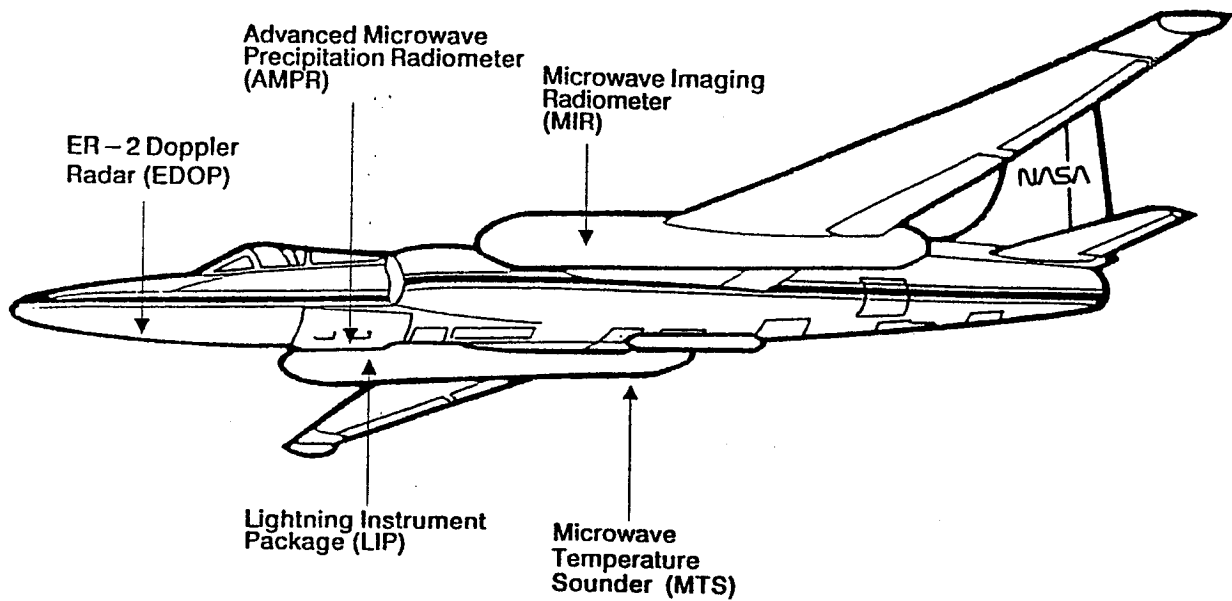
*An Example of Rocket-Triggered Lightning, performed at NASA Kennedy Space Flight Center.*

With this technique, small sounding rockets connected to long copper wires have replaced Franklin's kite. These rockets are launched into thunderstorms with electronic sensors located near the bottom end of the wire instead of a key. When the rocket is struck by lightning, the wire is vaporized.

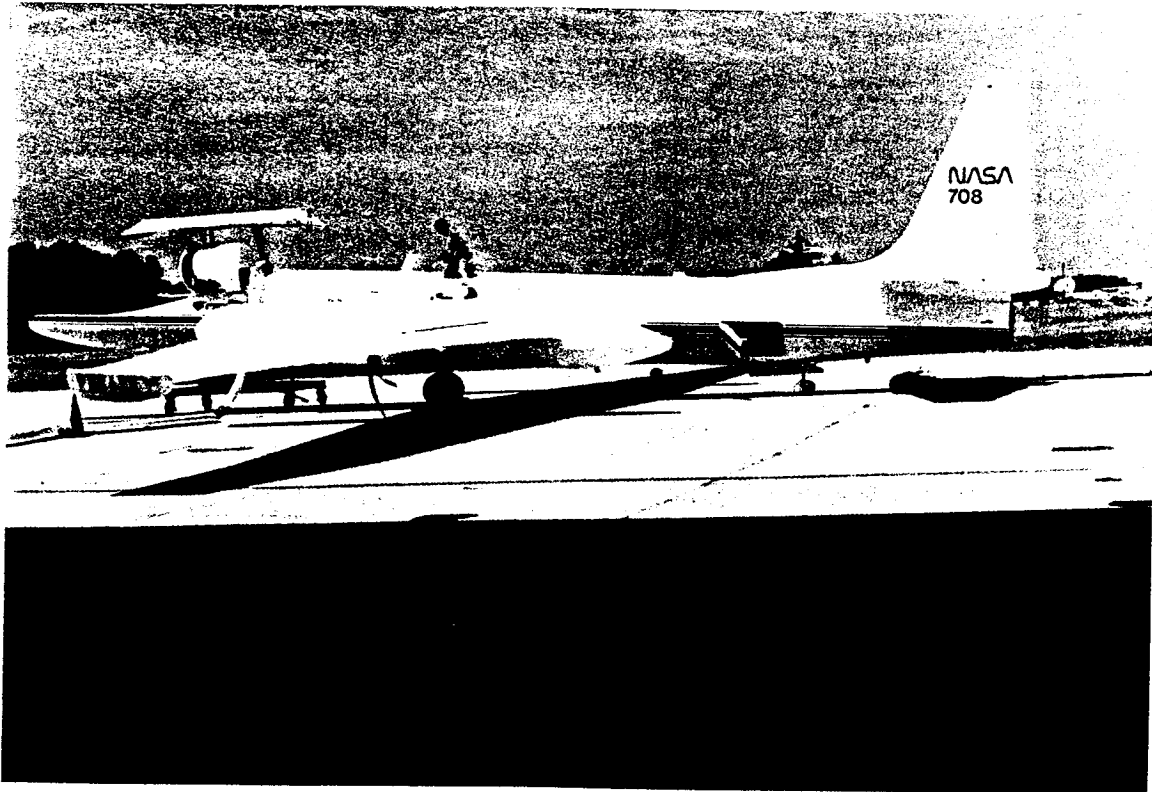
Data collected before and during the occurrence of lightning provide detailed information of the discharge's characteristics. Sounding rockets can also provide in-cloud measurements of thunderstorms in a challenging environment. While extensive ground-based optical and electrical measurements of lightning have been made, the emphasis has been on cloud-to-ground discharges with little study of intra-cloud lightning being undertaken. This is partly due to the fact that optical measurements of in-cloud lightning are severely affected by light scattering from water droplets within the cloud. For this reason, ground-based measurements alone have not been considered an appropriate means for determining the optical characteristics of lightning as viewed from above.

In order to determine the requirements for making optical measurements from space, U-2 and ER-2 high altitude airplanes have been used to study the electrical and optical characteristics of lightning activity in thunderstorms. Flying at an altitude of 20 km and at speeds of 200 meters per second, they are capable of flying over very large thunderstorms.

Much has been learned from these aircraft observations. For example, they have confirmed C. T. R. Wilson's theory that strong electric fields over the tops of thunderstorms cause conduction currents to flow to the tops of clouds. The penetrative convective cells which rise above the anvil are the most active electric regions in the storm and cause the most intense electrical stresses, as seen from high altitude aircraft.



## ER-2 Configuration for Storm Observations



**NASA ER-2 HIGH ALTITUDE AIRPLANE DEVELOPED BY LOCKHEED**

The ER-2 has a larger payload capability than the U2. Both have provided direct observations of severe thunderstorms and other clouds using multi-sensor payloads including lasers, infrared, visible, microwave scanners, spectrometers, and electric field antennas.

In addition, photography of lightning from above clouds has been accomplished using an open shutter technique. In this method, the camera is pointed toward the thundercloud with the shutter open. In the dark nocturnal sky, no light falls onto the film until lightning strikes.



*An example of an open shutter photograph from the U-2, a storm cell depicts a convective cloud turret with a cloud height of ~11 km illuminated by lightning ~12 km in diameter.*

To compliment the optical measurements from aircraft, video lightning images have been taken during a number of space shuttle flights. These observations have revealed many interesting lightning events.

For example, on April 28, 1990, a video image from space showed a single stratospheric luminous discharge appearing to move upward into clear night air. This was recorded on the space shuttle STS-32 mission using the payload bay TV camera.

The direction of this event has not been firmly established, however, the stratospheric discharge is of interest because it may provide evidence for a theory postulated by C. T. R. Wilson in 1925. This theory predicted that electric fields can cause ionization at great heights and could therefore give rise to discharges between clouds and the upper atmosphere.

Stratospheric lightning could potentially deposit significant energy into the stratosphere, causing important chemical perturbations. In addition, these lightning events may generate strong electric fields and electromagnetic pulses which might interact with the Earth's ionosphere and magnetosphere. Finally, strong fields at high altitudes may generate runaway electrons which could then produce high energy x-rays and even gamma rays. Thus, it is possible that lightning may generate electromagnetic radiation, ranging from extremely low frequency to gamma radiation.

Researchers from the Geophysical Institute at the University of Alaska have confirmed shuttle observations by capturing images on videotape of what appear to be brief flashes of light emanating from thunderstorms into the stratosphere. These "stratospheric optical flashes" were photographed from NASA's DC-8 Airborne Laboratory while flying at an altitude of about 12 km during a night-time mission to videotape lightning over Iowa and Kansas during June and July of 1993. Stratospheric flashes are brief, persisting for less than about a tenth of a second. They appear to be associated with intense thunderstorm activity, but are both rare and fainter than typical cloud-to-ground or intra-cloud lightning. Unlike familiar ground level lightning events that are electrical discharges confined to narrow channels, the flashes appear to cover a relatively broad horizontal extent of several miles, and to extend to altitudes of perhaps as much as 45 km, or about 30 miles.



## LIGHTNING DETECTION NETWORKS

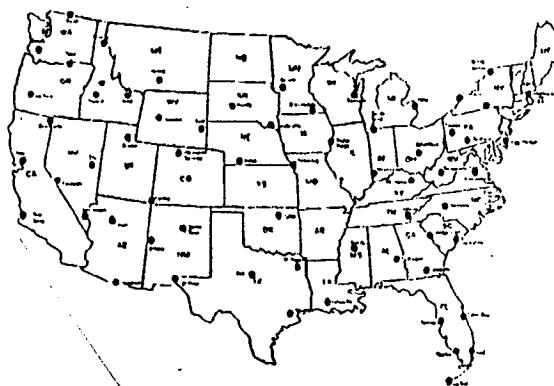
National and regional lightning networks which use magnetic direction finders, time of arrival techniques, or VHF interferometry, provide important lightning and storm information. For a number of years, the Federal Government assisted in the financing of a national lightning data service combining independently operated systems into one network. Used primarily for operational evaluation by NOAA, it evolved into a product with substantial value for both private industry and by other Federal agencies. By 1991, recognition of the importance of lightning detection had become apparent with economically viable commercially-sponsored systems coming into existence.

The National Lightning Detection Network (NLDN) which is operated by GeoMet Data Services, Inc. (GDS) in Tucson, Arizona, is a network of at least 130 magnetic direction finders which covers the entire United States. Each direction finder determines a direction toward a detected electromagnetic lightning discharge. The location of the lightning discharge is determined by triangulation. Each of these sensors is capable of detecting cloud-to-ground lightning flashes at a distance of 400 km away and greater. Processed information is transmitted to the Network Control Center (NCC) in the form of a grid map showing lightning across the U.S.

The Atmospheric Research Systems, Inc. (ARSI) time of arrival (TOA) system provides 11 Lightning Position And Tracking Systems (LPATS) which cover the U.S. and extend hundreds of miles into both oceans and beyond the borders of Canada and Mexico. ARSI ground strokes lightning data includes information on latitude and longitude, date and time, polarity, and amplitude.

Recently, GDS purchased the ARSI system, and is in the process of combining the direction finding and time of arrival techniques into a single comprehensive network.

The TOA system operates by digitizing the waveform of a received lightning signal at each sensor and accurately timing the peak with a resolution of up to 100 nanoseconds. The difference of arrival time at four or more receivers is then used to calculate the location. The geographical positions of the various sensors making up the network are shown in the U.S. map that follows.



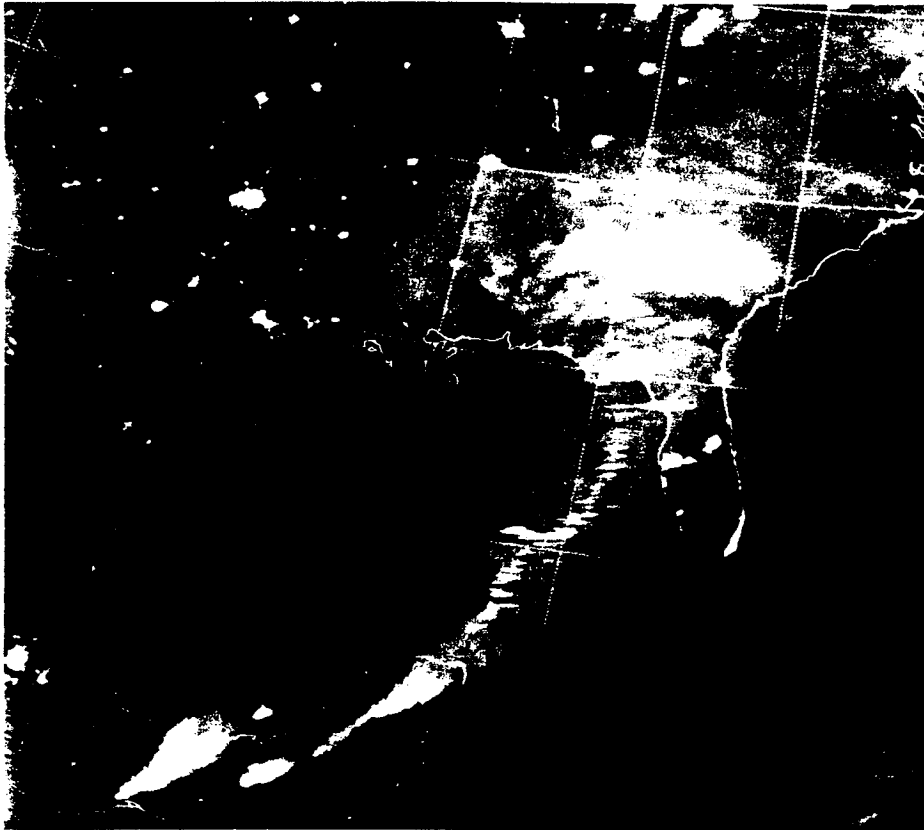
LPATS National Network: Receiver Sites

Internationally, two very different types of lightning detection and location networks have been developed. The SAFIR two-dimensional VHF interferometer system developed by the French aerospace research organization ONERA and commercialized by *Dimensions* of France, is used to provide detailed information on all types of lightning activity within a relatively small area. The VLF Arrival-Time Difference (ATD) system designed and operated by the United Kingdom Meteorological Office, detects and locates lightning at very long range, but with less detection efficiency. In addition, other networks cover portions of Europe, Asia, Australia, China, and Canada.

## GLOBAL STUDIES

Global lightning signatures from the Defense Meteorological Satellite Program (DMSP) Optical Linescan System (OLS) have been analyzed from the filmstrip imagery which is archived at the National Snow and Ice Data Center in Boulder, Colorado. These signatures show up as horizontal streaks on the film images. The location of each of these streaks has been digitized in order to develop a preliminary database of global lightning activity.

While the database continues to be enlarged, the available data are spotty, making a comprehensive history of global lightning behavior impossible to produce. However, direct digital OLS data are becoming available now which will greatly improve and expand the global lightning database which will be an important reference dataset for the Lightning Imaging Sensor (LIS) (see page 16).



*OLS DMSP 13 March 1993 0400 GMT*

*Lightning annual, interannual, and seasonal variations could then be compared with other global sets (e.g. precipitation; global and regional synoptic patterns) both to improve understanding of the role of lightning on a global basis and to use lightning as an indicator of global change.*



## TROPICAL RAINFALL MEASURING MISSION (TRMM)

Rainfall is at the heart of Earth's unique ability to sustain life as we know it. Vegetable, animal, and human life is controlled to a large degree by the availability of moisture. On the global scale, heat released by the condensation of water vapor is a principal cause of motion in the atmosphere. Tropical rainfall, due to its abundance, plays a significant role in this process.

The measurement of rainfall is a difficult challenge due to its high spatial and temporal variability. Tropical rainfall is especially difficult as it is relatively inaccessible to in situ measurements.

Scheduled for launch in August, 1997, TRMM will be a space-based system for measuring tropical rainfall and its variations. Its orbit is designed to be circular, at an inclination of  $35^\circ$  to the equator, and at an altitude of 350 km. The low altitude of TRMM will provide high resolution, thus, accurate rainfall measurement will be obtainable over very small areas of the globe.

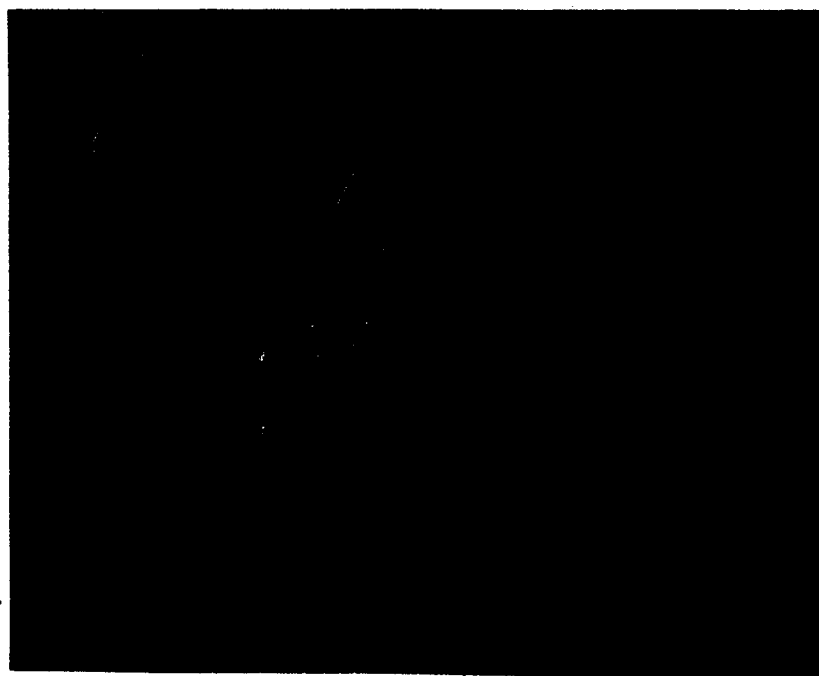
TRMM is an international collaboration with Japan, providing the first Precipitation Radar (PR) in space. The PR instrument will provide information on 3-D rainfall distributions over both land and ocean.

A multichannel microwave radiometer, referred to as the TRMM Microwave Imager (TMI), is designed to provide information on precipitation content, and the real distribution and intensity of rainfall.

The Visible Infrared Scanner (VIRS) will provide high resolution information on cloud coverage, type, and cloud top temperatures.

The Clouds' and Earth's Radiant Energy System (CERES) is a visible and infrared sensor designed especially to measure emitted and reflected radiative energy from the Earth, and from the atmosphere and its constituents.

The Lightning Imaging Sensor (LIS) will investigate the global incidence of lightning and the relationship of lightning to precipitation and other geophysical parameters (see pg. 16).



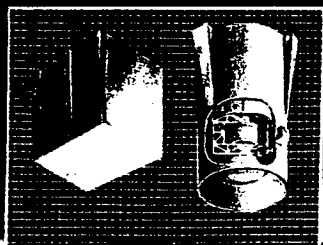
## LIGHTNING IMAGING SENSOR (LIS)

This instrument, scheduled to fly on the TRMM Observatory (pg. 15) has been designed to study the distribution and variability of total lightning on a global basis. It consists of a staring imager which is optimized to locate and detect lightning with storm-scale resolution of 5-10 km over a large region (600 x 600 km) of the Earth's surface. The field of view (FOV) is sufficient to observe a point on the Earth or a cloud for 80 seconds, adequate to estimate the flashing rate of many storms. The instrument records the time of occurrence of a lightning event, measures the radiant energy, and estimates the location.

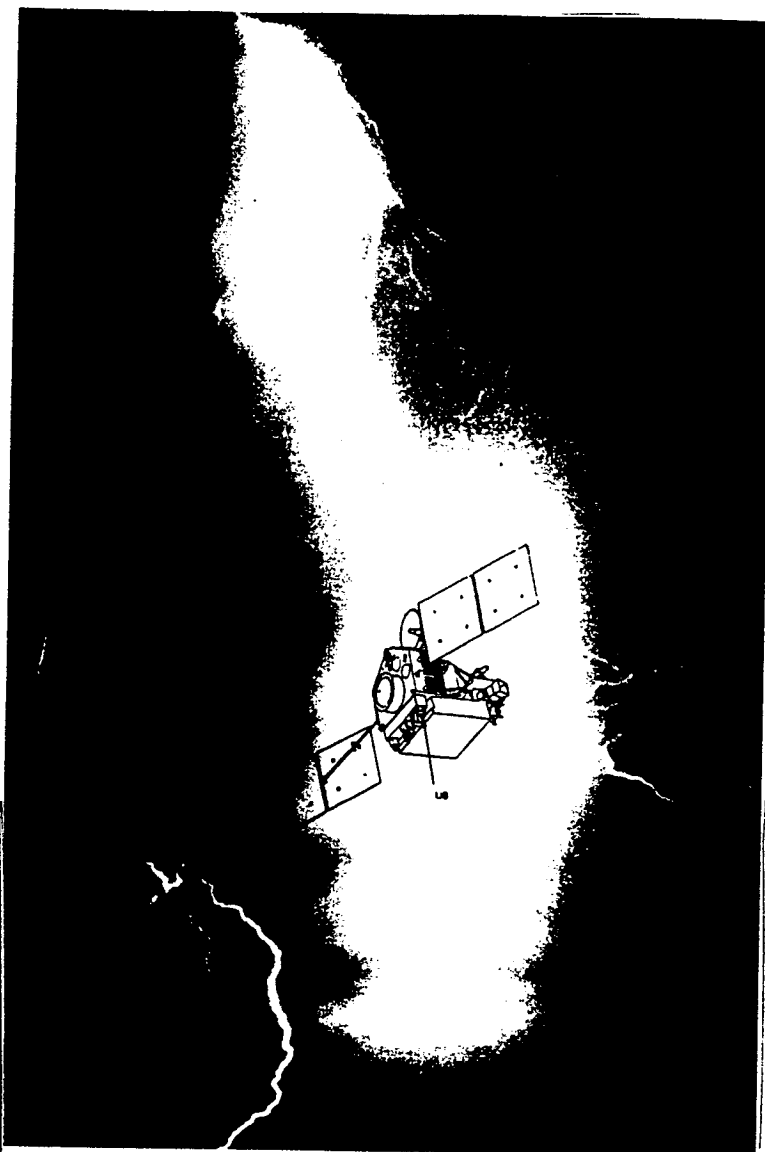
This calibrated lightning sensor uses a wide FOV expanded optics lens with a narrow-band filter in conjunction with a high speed charge-coupled device detection array. A real-time event processor (RTEP) is used to determine when a lightning flash occurs, even in the presence of bright sunlit clouds.

*Tropical Rainfall  
Measuring Mission  
(TRMM)*

*lightning  
imaging  
sensor*



Weak lightning signals that occur during the day are hard to detect because of background illumination. The RTEP will remove the background signal, thus enabling the system to detect weak lightning and achieve a 90% detection efficiency.



TRMM will study mesoscale phenomena such as storm convection, dynamics, and microphysics. These will be related to global rates and amounts and distribution of convective precipitation, as well as to the release and transport of latent heat, which are all influenced by global scale processes.

LIS will contribute significantly to several TRMM mission objectives by providing a global lightning and thunderstorm climatology from which changes (even subtle temperature variations) might be easily detected.

## OPTICAL TRANSIENT DETECTOR (OTD)

The Optical Transient Detector (OTD) is scheduled to be flown during the summer of 1994 as a precursor to LIS. It is actually an engineering model of LIS that has undergone extensive environment and performance testing in order to qualify it for space flight. The sensor will be integrated onto a small Micro-Lab 1 spacecraft and will be launched by a Pegasus vehicle from a L10-11 aircraft into a circular orbit of 780 km altitude and a 70° inclination to the equator. With this orbit, OTD will view a large area of the Earth's surface detecting far more lightning flashes with higher spatial resolution than ever before. OTD will continuously view a

given storm for three minutes or more, providing information on lightning flash rates and storm development. Most importantly, it will be the first space-based high resolution instrument to view lightning during the daytime as well as at night. Scientists will begin developing a quantitative, detailed global lightning climatic database in 1994. This will greatly advance scientific knowledge and will make it possible to use lightning as a variable in global change research during the early phase of the Earth Observing System (EOS) program which is the main element of NASA's *Mission to Planet Earth*.



Unique global data sets which LIS and OTD will provide include:

- DETECTION AND LOCATION OF INTENSE CONVECTION WITHOUT LAND-OCEAN BIAS
- ESTIMATION OF PRECIPITATION MASS IN THE MIXED PHASE REGION OF THUNDERCLOUDS
- DIFFERENTIATION OF STORMS WITH STRONG UPDRAFTS FROM THOSE WITH WEAK VERTICAL MOTIONS
- INFORMATION ON NATURAL NO<sub>x</sub> AND OTHER TRACE GAS PRODUCTION IN THE ATMOSPHERE
- DEVELOPMENT OF A GLOBAL LIGHTNING DATABASE AND CLIMATOLOGY
- QUANTIFICATION OF THE EARTH'S ELECTRIC CIRCUIT

## LIGHTNING MAPPER SENSOR (LMS)

The goal of the Lightning Mapper program is to place a sensor, capable of continuously mapping lightning discharges during both the day and night, with a spatial resolution of 10 km from geostationary orbit.

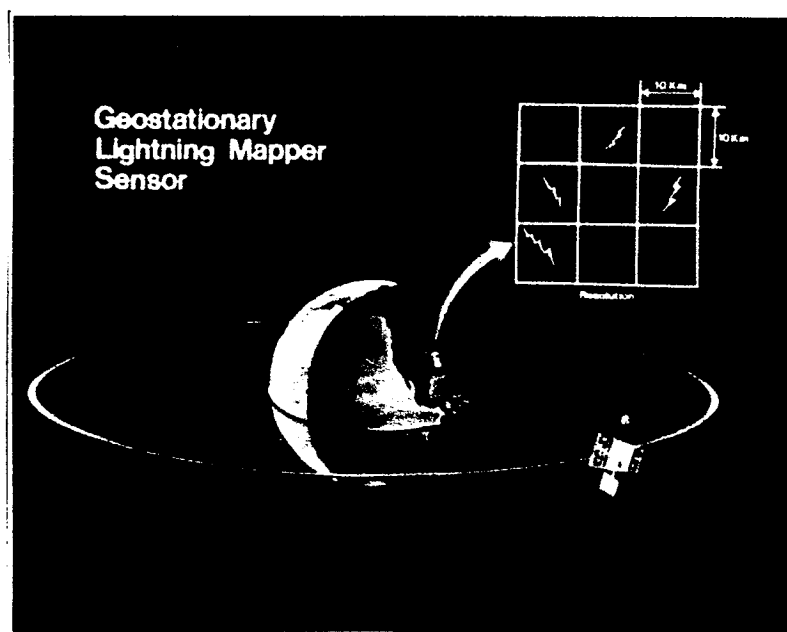
In a geostationary orbit, the Lightning Mapper Sensor will be capable of detecting and locating *both* cloud-to-ground and intra-cloud discharges with high spatial resolution and detection efficiency, i.e., detect and locate lightning with a storm-scale resolution over large areas of the Earth's surface.

With such an instrument, scientists will be able to study the electrosphere over dimensions ranging from the Earth's radius all the way down to individual thunderstorms. A Lightning Mapper Sensor would be capable of detecting all types of lightning phenomena, and will provide near uniform spatial coverage.

Disseminating this information in near real-time, these measurements could be related on a continuous basis to other observables such as radar returns, cloud images and other meteorological variables to enhance the accuracy of weather nowcasting.

The data will be used to determine flash rates, and storm motion and evolution. This will be correlated with information obtained from other sensor systems such as observations of precipitating electrons, VLF-ELF noise, and ULF waves in the ionosphere.

The LMS will provide information which can only be obtained with a space-based instrument. Because the data will be distributed in real-time, weather forecasters will find it an invaluable tool for storm nowcasting as well as for the issuing of severe storm warnings.



## **SOME USES OF A LIGHTNING MAPPER IN GEOSTATIONARY ORBIT**

1. Severe storm detection and warning (lightning, flash floods, tornadoes, hailstorms, and downbursts).
2. Convective rainfall estimation.
3. Storm tracking.
4. Aviation hazards (terminal and enroute use).
5. Hazard warnings: Power companies, fuel depots, golf courses, etc.
6. Algorithms for forest fire likelihood forecasting (uses location, frequency, and duration of flashes).
7. Can be used as an indicator of cyclone development and evolution.
8. Improvement of long-term forecasting by quantifying lightning activity for the time of day, season, location, and storm type.
9. Improvement in the understanding of the physics of the Global Electric
10. Increased understanding of lightning interactions with the magnetosphere and the ionosphere.
11. NO<sub>x</sub> generation studies.
12. Studies of whistler and other wave propagation phenomena.
13. Magnetospheric-ionospheric research.
14. Solar-tropospheric studies.



## THE FUTURE OF LIGHTNING DETECTION IN SPACE

Typically, more than 2,000 thunderstorms are active throughout the world at a given moment, producing on the order of 100 flashes per second.

As our society becomes more dependent upon computers and information networks (as well as various other electronic devices), protection from system disruptions becomes essential. One such protection comes from increasing our understanding of thunderstorms and how and why they occur.

The Lightning Mapper Sensor will assist in answering some of these questions. The knowledge from the studies described will strengthen the utility of NASA's Lightning Imaging Sensor and will add to the capability of a Lightning Mapper Sensor.

Most importantly, it will help us to better understand the Earth's atmosphere. As a response to fundamental forcing, lightning contains far more information than just the electrical aspects of the atmosphere. It tells us where strong convection is occurring, when large quantities of water are growing in the mixed phase regions of storms and suggests how latent heat is being released during the storm's life cycle. Since the microscales on which particles interact to

generate electricity are coupled through storm scale processes to synoptic scale systems, lightning activity should provide information on the development of the atmosphere over many scale sizes. Hopefully, with further study, we will learn to estimate convective rainfall rates from lightning flash rates, to identify local temperature anomalies from changing weather patterns and study developing weather systems by the evolution of lightning activity.

Investigations will continue to focus on the relationships between global and regional lightning activity and rainfall, linking electrical development to the environments of surrounding storms. Field programs in the tropics will provide ground-based data sets to be used in conjunction with radar, satellite, and lightning data, in order to develop and improve existing precipitation estimation algorithms, while providing a better understanding of the co-evolving electrical and dynamic structures of storms.

By better understanding all of the processes that lead to lightning, we will better understand the atmosphere and improve our ability to become wise tenants of the Planet Earth.

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**PRODUCTION & LAYOUT: Melanie A. McCook**



The six most common dangerous activities associated with lightning strikes, in order, are:

1. Work or play in open fields.
2. Boating, fishing, and swimming.
3. Working on heavy farm or road equipment.
4. Playing golf.
5. Talking on the telephone.
6. Repairing or using electrical appliances.

If caught in the open during a strike and the hair on your head or neck begins to stand on end (this really happens)



go inside the nearest building. If no shelter is available, crouch down immediately in the lowest possible spot and roll up in a ball with feet on the ground. (DO NOT LIE DOWN.)

#### TREATMENT:

- A. Check breathing and pulse .
- B. TREAT APPARENTLY DEAD FIRST .
- C. Perform mouth-to- mouth resuscitation.
- D. Apply cardiopulmonary resuscitation.

# **LIGHTNING IMAGING SENSOR (LIS)**

Scheduled to be launched on the Tropical Rainfall Measuring Mission (TRMM) Observatory in August 1997, LIS is designed to study the global distribution of lightning. Locating and detecting lightning flashes over a large area of the Earth's surface with storm-scale resolution of 5-10 km, LIS will record the time and radiant energy of each lightning event.

This calibrated lightning sensor uses a wide FOV expanded optics lens with a narrow-band interference filter to focus the image onto a high-speed 128x128 pixel charged-coupled device (CCD). Storms along the TRMM Observatory's orbital path will be observed for 80 seconds. By using multiple filtering techniques and a real-time event processor, weak lightning signals will be detected with high detection efficiency (>90%) despite the bright background caused by sunlight reflecting off of the tops of clouds.

LIS will contribute significantly to the overall mission objectives of TRMM. Lightning activity is closely related to storm updraft velocity and cloud microphysics, and can be correlated to amounts and distribution of precipitation and to the release and transport of latent heat. LIS investigations will increase our understanding of processes related to the amount, distribution, and structure of deep convection on a global scale; as well as the coupling between the intensity and frequency of thunderstorms and their seasonal and interannual variability.

## **PRODUCT**

Intensities  
Times of Occurrence and  
Locations of Lightning Events

## **EOS MISSION OBJECTIVES**

Cloud Characterization  
Hydrologic Cycle Studies  
Storm Convection  
Microphysics and Dynamics  
Seasonal and Interannual Variability of  
Thunderstorms

## **KEY FACTS**

In-House MSFC Development  
Under Development for Geostationary Orbit  
EOS-Funded Instrument for Launch on TRMM-1

## LIS PARAMETERS

View Direction	Nadir
Field of View (degs.)	80 x 80
Field of View (km)	600 x 600
Weight (kg)	20
Power (watts)	33
Telemetry (kbps)	6
Spatial Resolution (km)	5-10
Temporal Resolution (ms)	2
Wavelength (nm)	777.4

## LIS PERFORMANCE

Performance Driver: Solar Illuminated Cloud Tops  
Filtering Techniques: To Minimize Background

- Spatial - match pixel size to illuminated area
- Spectral - uses bandpass filter to isolate on an oxygen emission line
- Temporal - uses real time processor to remove slowly changing background

## MAJOR RESEARCH TOPICS

LIS studies will help determine the global distribution of lightning and lead to the formation of a climatic data base of the spatial and temporal distribution of lightning and thunderstorms.

LIS will help scientists understand the interrelationships between lightning and precipitation processes on a global basis and develop algorithms that incorporate these relationships into diagnostic and predictive models of the hydrological cycle and general circulation models.

LIS will improve understanding of the role of lightning and thunderstorms in the production, distribution, and transportation of trace gases in the atmosphere (e.g., NO<sub>x</sub>).

LIS will contribute toward determining the mechanisms for electrical coupling of lightning and thunderstorms with the ionosphere and magnetosphere that result from interactions with strong electric fields and electromagnetic waves.

It will improve scientific understanding of the Earth's global electric circuit by aiding in the quantification of electrical variables and determining their relationship to currents that flow within and near thunderstorms.

PHOTOGRAPH BY E.J. MILLS, Halifax

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## **OTD TECHNOLOGICAL INNOVATIONS**

### **Narrowband, refractory oxide interference filter**

- first space application
- very stable, low thermal coefficient, non-hydroscopic

### **Telecentric telescope**

- high speed (f/1.6) wide field of view

### **High-speed focal plane**

- 500 images/s

### **Real-Time Event Processor (RTEP)**

- dedicated hybrid computer analog & digital)
- processes 10 million pixels/s to extract
- lightning signals from bright background

**HIGH DETECTION EFFICIENCY (90%)**

**LOW FALSE ALARM RATE (<10%)**

**FLASH INTENSITY (+/-10%)**

**STORM SCALE RESOLUTION (10 km)**

**HIGH TEMPORAL RESOLUTION (2 ms)**

## **LOW-COST ACCESS TO SPACE IS ACHIEVABLE THROUGH**

Shared risk: Government/Private Sector  
Commercial satellite design heritage  
Streamlined instrument development

## **OTD PARAMETERS**

View Direction	Nadir
Field of View (degs)	80 x 80
Weight (kg)	2
Power (watts)	3
Telemetry (kbps)	6
Spatial Resolution (km)	10
Temporal Resolution (ms)	2
Wavelength (nm)	777.4

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National Aeronautics and Space Administration  
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# THE OPTICAL TRANSIENT DETECTOR (OTD)

An engineering model of the Lightning Imaging Sensor (LIS) which is scheduled to launch on the Tropical Rainfall Measuring Mission (TRMM), OTD will view a large area of the Earth's surface, detecting far more lightning flashes with much higher spatial resolution than ever before. OTD will continuously view a given storm for three minutes or more, providing detailed information on lightning flash rates and storm development. Most importantly it will be able to view lightning during the daytime as well as at night with high detection efficiency. Scientists will begin developing a quantitative and detailed global lightning climatic data base in 1994, making it possible to use lightning as a variable in global change research during the early phase of the Earth Observing System (EOS) Program, the main element of NASA's Mission to Planet Earth.

## OTD Research Topics

- ◆ Global distribution of lightning and thunderstorms
  - spatial
  - temporal
- ◆ Relationship between lightning and precipitation processes
- ◆ Role of lightning and thunderstorms in production, distribution, and transportation of trace gases (e.g., NO<sub>x</sub>)
- ◆ Mechanisms for electrical coupling of lightning and thunderstorms with
  - ionosphere
  - magnetosphere
- ◆ Global electric circuit

## OTD DEMONSTRATES KEY TECHNOLOGIES

- small satellite
- real time event processor
- charge-coupled device
- narrowband optical filter

## HIGH RESOLUTION LIGHTNING DETECTION

- Daytime
- Nighttime

OTD will be launched on the MicroLab I Satellite built by Orbital Sciences Corporation of Dulles, Virginia in 1994.

NASA

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Space Agency

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